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November 1978

Annual Summary of O.N.R. Contract

No. N 00014-76-C-0014

Marvin H. Mittleman, Principal Investigator

Areas of Research CONTENTS:

~~A.~~ Configuration space Hamiltonian for Heavy Atoms;

~~B.~~ Laser-Atom Interactions;

~~(i)~~ Electron-Atom Scattering in the presence of a laser field; for resonant laser frequency and for low laser frequency;

~~(ii)~~ Resonance Fluorescence, and

~~C.~~ Statistical Model of Atom-Atom Scattering.

Progress Report and Description of Proposed Research

A. Configuration Space Hamiltonian for Heavy Atoms.

Work in this area is proceeding. I spent last summer at the FOM Laboratory for Atomic and Molecular Physics in Amsterdam. Dr. M. Gavrilla, a staff member there and I spent a good deal of time reviewing Russian work in this area. Some of their untranslated publications were reworked and found to be of little interest. There is however some theoretical work relevent to the collision of heavy ions and the "diving problem" which is good but only relevant to the few electron problem and not the heavy neutral atom.

My plan to discuss the problem with Prof. Janos Ladik of the University of Erlangen, Germany this summer did not materialize but he is visiting City College for a couple of months now and we have discussed the problem extensively. He is a Quantum Chemist and primarily interested in the calculational aspects of the problem so we complement each other well. We are planning further collaboration next summer, perhaps in Germany. He is also planning a small workshop for the various people interested in the field next year.

My own work is continuing: I have formulated the problem of obtaining the optimum configuration space Hamiltonian for a heavy atom. The optimization is carried out within the constraint of allowing only one vertual pair of positive and negative frequency quanta of the electron positron field to

occur. A further constraint is the allowance of the exchange of only one transverse photon. The optimization is carried out with respect to the definition of the "electron" and "photon". These definitions introduce an arbitrary potential in the Dirac equation which defines the complete set of states in which the electron - positron field is quantized. They also introduce an arbitrary dielectric constant into the Maxwell equations which defines the photon states in terms of which the electromagnetic field is quantized. Both have been treated variationally and defining equations have been obtained. These are extremely complicated and work is now being carried out to try to simplify them.

I have applied for NASA support for a graduate student who will work on this program.

B. Laser-Atom Interactions

(i) Electron-Atom Scatttering

I have published three papers [1,2,3] on this subject this year, and a fourth[4] is being submitted now. The first describes the theory of an experiment by Van der Weil[5] and his group at the FOM lab. An electron was scattered off Ne at a resonance energy in the field of a laser which was tuned so that obsorbtion of a single photon by the Ne resonance resulted in a higher Ne resonance. The theory gave the obvious result of a Breit-Wigner shape (as a function of the laser frequency) for each dipole connected pair of resonances. But I also found the possibility of interference of two different scattering

processes. The interference is the result of a virtual absorbtion of a photon by the projectile. The experiment as done used a laser which was too weak to observe the interference but Van der Weil is getting a more intense laser which may make the observation possible.

The second paper[2] is a reworking of the Kroll and Watson[6] calculation of electron-atom scattering in the field of a low frequency laser. The importance of the paper is primarily methodology. I found another and more systematic way of doing their calculation which allowed me to obtain second order results, (They only obtained first order) but more important it led to the possibility of using atomic targets rather than just potentials as targets. This led to the third paper.

The third paper[3] is a model calculation of electron-atom scattering in a low frequency laser. The model is that of a two state target. The cross section was obtained as a power series in ω, the laser frequency. The result is a generalization of the Kroll-Watson result for potential scattering. The important result is that the cross section is altered from the potential scattering result (due to atomic distortion by the laser) in <u>lowest order</u> in ω. The model is incomplete in that exchange scattering was neglected and the effect of the atomic continuum was omitted. The first of these (exchange) will give a contribution in the first order correction (as a power series in ω) to the cross section. This

is particularily important because of another (unpublished) result which I obtained.

The potential scattering result of Kroll and Watson can be used to find the average number of photons transferred between the electron and the laser during the scattering event. The result has been obtained as a power series in ω and, in lowest order, it comes from the first order correction to the cross section. (Note that exchange scattering would contribute in this order). The result can have either sign. That is, the electron can either absorb or emit energy into the laser mode. The details depend on the momentum transfer cross section of the electron scattered from the potential. This could have some practical applications so the first part of my work this year will be to try to obtain a similar result for the scattering of an electron from a real atom.

The paper about to be submitted[4] describes the theory of an experiment which is a logical out-growth of the experiment by Van der Weil. The new experiment, suggested by Bob Compton while he was at the FOM lab this summer, will be performed shortly at Oak Ridge. The idea is to scatter an electron off an atom at a resonance energy in a laser field but now the laser will induce an emission of a photon rather than an absorbtion as in previous experiment. The emission can result in a negative ion as the final electron state. This would allow negative ion spectroscopy with a resolution which is the laser line width, something which was not possible before.

Further theoretical work must wait for the experimental results

In earlier series of papers[7], I obtained the cross section for electron-atom scattering in the field of a laser when the laser is resonant with a transition in the free atom. In the weak laser limit the cross sections are merely multiples of cross sections in the absence of the laser. Experiments in more intense lasers are now being contemplated so the theory should now be extended to cover this case. The first appearance of new effects will be virtual absorbtion and emission of laser photons by the projectile. This will introduce new channels for the scattering and with it the possibility of interference with the old ones.

(ii) Resonance Fluorescence

The program described in last year's proposal is being finished up. My graduate student, Mr. James Kourlas, has calculated the shape of fluorescent spectrum when a linearly polarized laser pumps a $S_{1/2} \rightarrow P_{3/2}$ transition. He has included the possibility of splitting the states with a small D.C. Magnetic field and has also performed a calculation which includes the effects of laser fluctuations and drifts on the shape of the spectrum. He should finish this academic year.

C.Statistical Model of Atom-Atom Scattering

Years ago Wilets and I presented[8] a statistical theory of single ionization in atom-atom scattering. The model is supposed to apply to the situation in which level crossings are

dense and it gave good agreement with experiment for heavy atom pairs. The model has recently been applied[9] with good results to K shell excitation in atom-atom scattering The interpretation of the results as a success of the model is somewhat shakey[10] since K shell levels do not meet the criterion for validity of the model, dense level crossings. A more reasonable interpretation of the experiment is that of a two step process:first a vacancy is created in an upper level and then the K shell excitation is effected by promotion to this vacancy. The first step may reasonably be described by the statistical model but the promotion must be described by something akin to the Landau-Zener model.

This is a two step process, and a rather complex one. The statistical model has previously not been applied to anything but a single electron process so I am now applying it to the simplest two step process, double ionization. The equations have been written down and numerical work is now in progress to obtain both differential and total cross sections.

If this is successful I'll turn to the K shell excitation problem.

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6. N.M. Kroll and K.M. Watson, Phys. Rev. A 8 804 (1973)

7. Marvin H. Mittleman, Phys. Rev. A 16 1549 (1977)

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10. This conclusion has been reached independently by Dr. F. Saris of the FOM lab who is doing similar experiments.